Reprinted from
ERGONOMICS, Vol. 8, No. 3, p. 321, July, 1965

ENERGY EXPENDITURE OF SOLDIERS PERFORMING COMBAT TYPE ACTIVITIES

By R. F. GOLDMAN
U.S. Army Research Institute of Environmental Medicine
Natick, Massachusetts

The energy cost of a number of tactical tasks was measured for soldiers during tactically controlled rather than experimentally controlled tasks. The upper range of energy expenditure rates was 400 to 450 kcal per hour during these tactical manoeuvres; incipient physical or heat exhaustion was associated with the few much higher values. The realism of the tactical situation, and an estimate of the contribution made by the heat load and wearing of the gas mask to the energy costs measured is presented. The hypothesis is presented that the upper range of energy expenditure rates for prolonged periods is independent of terrain when men are allowed to work at their own pace, but depends on the total weight carried. The relationship between ventilation volume and energy expenditure in this study is compared with data presented by Liddell and supports the argument that calculation of energy expenditure can be reliably made using a single formula to convert ventilation volume *per se*, particularly within the practical accuracy of field measurements.

§ 1. INTRODUCTION

STUDIES on the energy expended by the soldier were among the earliest non-clinical investigations in the area of applied physiological research (Brezina and Kolmer 1912). Work in this and related areas has been progressive with several excellent reviews of the subject (Redfearn *et al.* 1956) and even some mathematical predictions formulated (Bobbert 1960, Goldman and Iampietro 1962). However, as one might expect, there are few values for the energy expenditure of soldiers in activities simulating those in combat. The few that exist are for carefully defined activities done under the control and direction of the experimenter rather than under military tactical control (Daniels *et al.* 1953, 1954). Thus data exist for the energy cost of marching at various speeds with and without loads, for rifle drill, for infantry rushing and the like. These data have been helpful in understanding the factors involved in tactical situations. However, the energy expended by troops performing a tactical mission has had to be deduced from assumptions as to the load, type of activity and length of time needed to accomplish each activity.

An infantry exercise conducted by the U.S. Army Combat Development Command Experimentation Center in January 1963, in Panama, afforded the opportunity to make a number of energy expenditure measurements during tactically, rather than scientifically controlled activities. These measurements on conditioned troops employed tactically in simulated combat missions by seasoned infantry commanders are the subject of this report.

§2. METHODS

Thirty-eight measurements were obtained on 24 infantrymen assaulting and attacking a hill under aggressor fire, digging in, clearing mines, emplacing mortars and patrolling jungle areas. The average ambient wet bulb globe temperature (WBGT) index* was 83 during these measuring periods.

* WBGT = 0·7 T wet bulb + 0·2 T globe + 0·1 T dry bulb (°F)

Heat acclimatized troops in good physical condition were weighed nude and then again with the total load to be carried in the problem. Thus, in this study, ' load ' includes the clothing, weapon, ammunition and anything else that the squad leader instructed the individual soldier to carry. A two-layer clothing system was worn, consisting of chemically impregnated long underwear and an impregnated fatigue jacket and trousers*; the impregnation limited the evaporation of sweat and therefore a heat load was incurred when the subjects were working. Gas masks were worn on most days, with each subject's mask carefully checked for fit and function before each measurement. After being weighed, the subjects were returned to the control of the infantry officers and non-commissioned officers who conducted the tactical problems.

The sequence of tactical events for the rifle platoon in the attack problem was: walk 3 min to an assembly area; occupy it for 30 min while digging or improving ' foxholes ' in a leisurely manner; move out and route step road march at 5·5 to 6·5 km per hour for about 35 min; encounter aggressor fire and the platoon disperse; assault a hill, drive off the aggressor (5 min); reorganize (5 to 10 min); assault down the hill, across 150 m of valley and up a steep (60°) fairly high (20 m) hill which served as a final objective (5 min). The terrain was hilly, relatively free of brush, generally dry and firm underfoot; the road was compacted dirt with only a mild grade.

The jungle infantry problems involved walking slowly, single file on a narrow dirt trail through the jungle, halting frequently; exchanging fire with aggressor troops while moving rapidly off the trail and counter-attacking through the jungle forest.

When the 81 mm mortar was handled, in or out of the jungle, it was initially emplaced; then it was knocked down and the components were displaced and ' back-carried ' about 2 km in 30 min and finally it was re-emplaced.

A low resistance respiratory valve with special mouthpiece was used on the few days that the gas mask was not worn. An exhaust port adapter was used to channel the expired air when the mask was worn. Energy expenditures were determined using a *Müller-Franz* respiratory air meter to take a timed respiratory volume measurement and collect a 0·6 per cent aliquot of each expired breath in a rubber sampling bag. The rubber sampling bag was taken by jeep to a tent laboratory and the oxygen content of the expired air was measured within 20 min of collection, using a *Beckman Model E* paramagnetic oxygen analyzer. Caloric expenditure was calculated using the method suggested by Weir (1949).

§ 3. Results

The assignments, loads and characteristics of the subjects are presented in Table 1. The average infantry rifleman's load was slightly over 20 kg, where load is added to the nude weight. Platoon and squad leaders and company medical aidmen carried an additional 2 kg of equipment. The personnel of the heavy weapons squad were more heavily loaded, a machine gunner carrying 32 kg, while a 90 mm recoilless rifleman carried 35 kg or more, as did the infantry radio-telephone operator and most mortarmen. The individual measurements of energy expenditure are also presented in Table 1.

* The current U.S. standard chemical-biological protective ensemble.

Table 1. Subject characteristics, loads carried, tasks measured and the respiratory and energy cost data

Subject No.	Age (yrs)	HgT (cms)	Nude wgt (kgs)	Load* (kgs)	Load as % body wgt	Assignment	Task	Collection (mins)	R.M.V. (l/min STPD)	FE_{O_2} (%)	Energy cost (kcal/min)
7	32	170	62·5	22·7	37	company commander	trooping ridge positions	4	36·8	17·0	7·3
13	23	173	71·1	19·7	27	rifleman	jungle patrol	5	23·4	17·7	3·8
							jungle patrol	10	22·7	17·4	4·0
							jungle fire fight	5	38·7	17·2	7·3
15	20	174	79·6	22·0	28	rifleman	approach road march	10	20·0	17·1	3·8
18	22	184	84·8	20·0	24	medical aidman	littering 80 kg man	3	33·7	16·8	7·0
19	22	182	82·6	23·5	29		littering 80 kg man	3	34·7	17·1	6·6
							littering 80 kg man	5	32·0	16·8	6·5
20	20	166	58·9	22·4	38	litter bearer	halted on jungle trail	6	15·6	17·8	2·4
							jungle patrol	5	15·5	16·6	3·4
							jungle patrol	6	16·2	16·8	3·3
21	30	171	62·8	31·7	51	machine gunner	jungle patrol with 2′ halt	5	29·1	18·3	3·8
							jungle patrol	7	26·8	17·4	4·7
							jungle patrol	5	25·2	16·7	5·4
							jungle fire fight	1	46·0	16·7	8·0
25	31	168	56·4	23·9	42	engineer	mine clearing squad leader	10	14·0	17·3	2·6
29	24	175	82·5	20·0	24	engineer	probing for mines	10	11·5	17·0	2·3
30	18	164	68·1	21·7	32	engineer	mine sweeper operator	10	13·9	16·7	2·9
42	22	169	66·2	34·4	51	radiotelephone operator	approach road march	5	17·4	16·1	4·2
46	23	157	66·7	19·8	32	rifleman	rear area foxhole digging	5	14·6	15·5	4·0
49	24	174	74·4	20·2	30	rifleman	forward area foxhole digging	3	30·4	16·6	6·6
52	19	168	55·8	20·5	39	rifleman	assault 1st objective	3	32·8	16·8	6·8
							assault final objective	2	38·6	17·3	7·0
							resting 2′ after assault	10	13·3	18·1	1·8
54	21	179	77·9	24·1	32	asst. machine gunner	forward area foxhole digging	3	27·8	16·0	6·8
							rear area foxhole digging	5	21·8	17·1	4·2
55	20	171	75·1	28·2	53	90 mm recoilless rifleman	forward area position digging	3	28·9	15·6	7·7
60	24	171	65·1	24·3	41	rifleman	resting 2′ after assault	3	21·4	18·6	2·5
61	29	176	71·4	36·2	52	81 mm mortarman	jungle march	6	33·8	16·9	6·8
							jungle march	5	35·6	16·9	7·2
63	24	176	78·5	38·3	49	81 mm mortarman	jungle march	5	38·4	17·0	7·6
66	33	170	94·8	38·2	41	81 mm mortarman	approach road march	6	40·2	17·0	8·0
67	21	168	59·4	33·4	57	81 mm mortarman	approach road march	4†	34·2	15·0	10·1
71	21	174	67·6	20·8	31	rifleman	jungle patrol	6	24·0	17·6	4·0
							jungle scout	3	27·5	17·6	4·6
							jungle scout	6	25·4	17·1	4·8
89	21	185	91·6	31·1	35	machine gunner	approach road march	6	23·6	17·0	4·7
90	24	169	73·8	34·8	47	90 mm recoilless rifleman	begin assault	2†	51·3	18·0	7·6

* Loads in the jungle patrol for infantrymen were approximately 27% less; the load of a mortarman was reduced only about 10% in the jungle.
† Subject near collapse, rectal temperature 39·5°C.

The energy costs of the various tactical activities measured are arranged in Table 2 as a function of both load and task. The simulated fight where men left the jungle trail and attacked through the jungle forest, was more demanding than the uphill assault on open ground, even though the load in the jungle was 27 per cent lighter. Both activities required energy expenditure rates in excess of 7 kcal/min but seldom lasted more than 10 min. The energy expenditure rates measured for infantrymen in the jungle patrol, despite a slower pace, frequent halts, and lighter loads (27 per cent) were not much different from rates for the same type work in the open country, *i.e.*, marching, where traffic-ability of the terrain was better. The mine clearance task, since it was performed at a painstakingly slow pace, took very little more energy than standing at rest with an equivalent load.

Table 2. Relative energy costs (kcal/min) as a function of load and task

Assignment	Load (kg)	Resting	Clearing	Patrol	Pointman in jungle	Approach road march	In assault	In jungle fire fight
Rifleman	20	2·2	2·6	3·8	4·8	—	6·9	7·3
Machine gunner	32	—	—	5·0		4·7	—	8·0
90 mm recoilless rifleman	38	—	—	—	—	—	7·6	—
81 mm mortarman	40	—	—	7·0		8·0	—	—

Respiratory minute volumes (STPD) were obtained as part of the energy expenditure measurements and are presented in Figure 1 as a function of energy expenditure. A dashed line representing the relationship between respiratory volume and energy expenditure for a group of coal miners (Liddell 1963) is included for comparison with the solid line which represents the least squares best fit regression for the present data.

§ 4. Discussion

The approximation to the real life situation of combat in this study was as close as possible in terms of task and command control. However, unavoidably lacking was the fear and fatigue of true combat. The upper range of energy expenditure rates in this study was about 6·7 to 7·5 kcal/min. A few individuals exceeded this range; for them the physical inefficiencies of incipient exhaustion (physical and or heat) became evident. It seems doubtful that an average individual would voluntarily work at the classic 'maximum aerobic work capacity' as defined in the laboratory, *i.e.* a 10 kcal per minute rate for a one hour period (Lehmann 1953). Energy expenditure rates of about 8 kcal/min have been reported for lighter weight troops running a short assault course (Malhotra *et al.* 1962) at their own pace.

The contribution of the respiratory impedance of the gas mask to the measured energy expenditure is difficult to estimate. Any device used in collecting expired air will present some respiratory impedance. The expiratory impedance of the gas mask, with a simple rubber flap valve leading to the gasometer hose, probably does not differ from that of the usual collection technique; however, the inspiratory impedance may be considerably higher

than usual. Since the mechanical efficiency of breathing is only about 5 per cent (Otis 1954), the constraint of the gas mask may represent a significant portion of the energy cost of breathing even through a modest per cent of the total.

The heat load induced by the high work rate while wearing protective clothing in the 83 WBGT index environment (Goldman 1963) resulted in elevation of body core temperature and thereby may have produced a temperature-induced increase in metabolic rate. The subjects may also have been somewhat dehydrated since no water intake was possible during the two hours of gas mask wear. The resultant load on the cardiovascular system of both these effects may have increased the energy cost (Adolph 1947, Astrand 1960), but again probably represented only a small percent of the total.

Table 3. The energy cost of various tactical tasks

Task-situation	Mean energy cost (kcal/min)	No. of measures (n)	Range (kcal/min)
Rifleman resting on top of final objective 2′ after assault	2·2	2	± 0·3
Mine clearance of road—probing	2·3	1	
—squad leader c radio	2·6	1	
mine sweeper operator	2·9	1	
Infantry litter bearers—in jungle patrol	3·4	2	± 0·03
Riflemen—in jungle patrol	3·8	4	± 0·5
Rifleman—in jungle patrol as pointman	4·8	2	± 0·1
Infantry radio telephone operator—on approach road march	4·0	2	± 0·2
Rifleman—digging foxhole in rear area	4·1	2	± 0·1
M-60 machine gunner—on approach road march	4·7	1	
M-60 machine gunner—on jungle patrol	5·0	2	± 0·3
Litter bearers—littering 80 kg casualty on road	6·7	3	± 0·3
Rifleman—in assault	6·9	2	± 0·1
Rifleman—digging foxhole in forward area	7·0	3	± 0·6
81 mm mortarman—march to emplace in jungle	7·0	4	± 0·4
Company Commander—trooping ride line positions	7·3	1	
Rifleman—in fire fight in jungle	7·3	1	
90 mm recoilless rifleman—in assault	7·6	1	
81 mm mortarman—road march to emplace	8·0/10·1*	2	
M-60 machine gunner—in fire fight in jungle	8·0	1	

* At point of exhaustion, rectal temperature 39·5°C (103°F); could not continue.

The fact that these energy cost values were independent of local terrain is worth discussion. In the present study, progression rate was not closely controlled but was at the discretion of the soldier. Although the data is quite limited, the narrow range of the several measurements of each task (Table 3) in spite of variations in the geographic site of measurement, may contribute support to the suggestion that when individuals are allowed to work at their own pace, difficulties in work are compensated for by the rate at which it is performed (Astrand 1960).

Finally, the relationship between ventilation volume and energy expenditure for this group is linear and the slope corresponds well with Liddell's on coal miners doing walking tasks (Liddell 1963). The difference in absolute values between these two groups may be a function of age, loads and distribution of loads. The small magnitude of this difference, particularly at ventilation volumes above 30 litres per minute, supports the argument that estimation

of energy expenditure from pulmonary ventilation alone, by a single formula, is acceptable. However, the large divergence of the two points in Figure 1 representing the data from the two subjects near collapse (subject 71 : 10·1

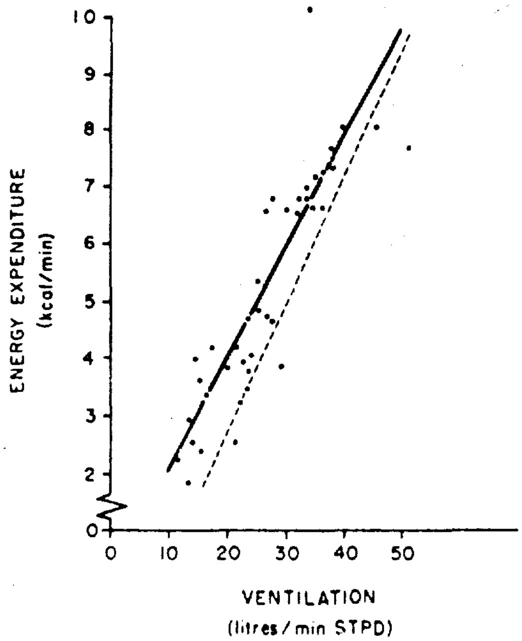

Figure 1. Relationship between respiratory minute volume (STPD) and energy expenditure for this study (solid line) and for a group of coal miners (Liddell 1963) (dashed line).

kcal and 34·2 l/min; subject 90 : 7·6 and 51·3 l/min) indicates that a large error can occur when an estimate of energy expenditure from ventilation volume is attempted for severely stressed individuals.

The author wishes to acknowledge the contributions of Major Robert J. T. Joy, M.C., U.S.A., Messrs. John Breckenridge and Harold Hanson, who, by taking on extra work, provided the author with time to carry out this study.

Le coût énergétique d'un certain nombre d'exercices tactiques a été mesuré chez des soldats exécutant une tâche contrôlée plutôt du point de vue tactique du point de vue expérimental. Au cours de ces manoeuvres, le niveau des dépenses d'énergie les plus élevées qui furent observées s'étendait de 400 à 450 Kcal par heure: l'apparition d'un épuisement physique ou thermique était lié aux rares valeurs qui dépassèrent de beaucoup ces chiffres. Les auteurs décrivent en détail le déroulement réaliste de ces manoeuvres, et donnent une estimation de la part qui revient à la charge thermique et au port du masque à gaz dans le coût énergétique mesuré. Ils émettent également l'hypothèse que le niveau de la gamme des dépenses d'énergie les plus élevées et observés lors de périodes prolongées est indépendant de la nature du terrain à condition que les hommes puissant travailler à leur rythme propre, mais dépend du poids total de la charge transportée. La relation existant entre le débit ventilatoire et la dépense d'énergie mesurés dans cette étude a été comparée aux données présentées par Liddell: elle étaye l'argument selon lequel le calcul de la dépense d'énergie à partir du seul débit ventilatoire peut être effectué en toute sécurité à l'aide d'une seule formule, surtout dans la marge de précision pratiquement permise par des études sur le terrain.

Der Energieaufwand für eine Reihe von taktischen Aufgaben wurde an Soldaten bestimmt; die Aufgaben waren eher taktisch als experimentell kontrolliert. Die Spitzenwerte des Energieaufwandes während dieser taktischen Manöver lagen bei 400 bis 500 kcal/Stunde; beginnende physische oder Hitze-Erschöpfung ergaben sich bei den wenigen viel höheren Werten. Eine Schätzung der Wirklichkeitsnähe der taktischen Situation und des Einflusses der Hitzebelastung und des Tragens der Gasmaske auf den gemessenen Energieaufwand wurde vorgenommen. Es wurde die Hypothese aufgestellt dass die Spitzenwerte des Energieaufwandes über längere Perioden

vom Terrain unabhängig sind, wenn die Soldaten nach ihrem eigenen Tempo arbeiten dürfen, dass diese Spitzenwerte dagegen vom gesamten transportierten Gewicht abhängen. Die Beziehung zwischen Ventilationsvolumen und Energieaufwand in dieser Untersuchung wurde mit den von Liddell veröffentlichten Daten verglichen. Sie unterstützt die Auffassung, dass die Berechnung des Energieaufwandes verlässlich aus dem Ventilationsvolumen je Sekunde mit einer einzigen Formel speziell in Feldversuchen mit praktisch genügender Genauigkeit erfolgen kann.

References

ADOLPH, E. F., 1947, *Physiology of Man in The Desert*. (New York: Interscience, Inc.).

ASTRAND, I., 1960, Aerobic work capacity in men and women with special reference to age. *Acta Physiol. Scand.*, **49**, Suppl. 169.

BOBBERT, A. C., 1960, Energy expenditure in level and grade walking. *J. appl. Physiol.*, **15**, 1015–1021.

BREZINA, E. and KOLMER, W. 1912, Über den energieverbrauch beider geharbeit unter dem einflussverschiedener geschwindigheiten und verschiedener belastungen. *Biochem. Ztschr.*, **38**, 129–153.

CATHCART, E. P. and ORR, J. B., 1919, *Energy Expenditure of the Infantry Recruit in Training*. (London: Her Majesty's Stationery Office).

CRAIG, F. N., 1957, Performance capacity under conditions of chemical warfare. In *Symposium on Performance Capacity* (Edited by H. S. Spector) (Chicago: U.S. Army Quartermaster Food and Container Institute).

DANIELS, F. Jr., VANDERBIE, H. and WINSMANN, F. R., 1953, Energy cost of treadmill walking compared to road walking. *Natick QM R & D Lab. Rpt.* 220.

DANIELS, F. Jr., LYMAN J. and VANDERBIE, J. H., 1954, A Review of methods for studying load-carrying systems. *Natick QM R&D Lab. Rpt.* 225.

GOLDMAN, R. F. and IAMPIETRO, P. F., 1962, Energy cost of load carriage. *J. appl. Physiol.*, **17**, 675–676.

GOLDMAN, R. F., 1963, Tolerance time for work in the heat when wearing CBR protective clothing. *Mil. Med.*, **128**, 776–786.

LIDDELL, F. D. K., 1963, Estimation of energy expenditure from expired air. *J. appl. Physiol.*, **18**, 25–29.

LEHMANN, G., 1953, *Praktische Arbeitsphysiologie*. (Stuttgart: Thieme Verlag).

MALHOTRA, M. S., RAMASWAMY, S. S., and RAY, S. N., 1962, Influence of body weight on energy expenditure. *J. appl. Physiol.*, **17**, 433–435.

OTIS, A. B., 1951, The work of breathing. *Physiol. Rev.* **34**, 449–458.

PASSMORE, R. and DURNIN, J. V. G. A., 1955, Human energy expenditure. *Physiol. Rev.* **35**, 801–840.

REDFEARN, J. W. T., CRAMPTON, R. F. WILLIAMS T. D. and MITCHELL, B., 1956, The Metabolic cost of load carriage. *British Army Operations Research Group Rpt.*, 4/56.

WEIR, J. B. de V., 1949, New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.*, **109**, 1–9.